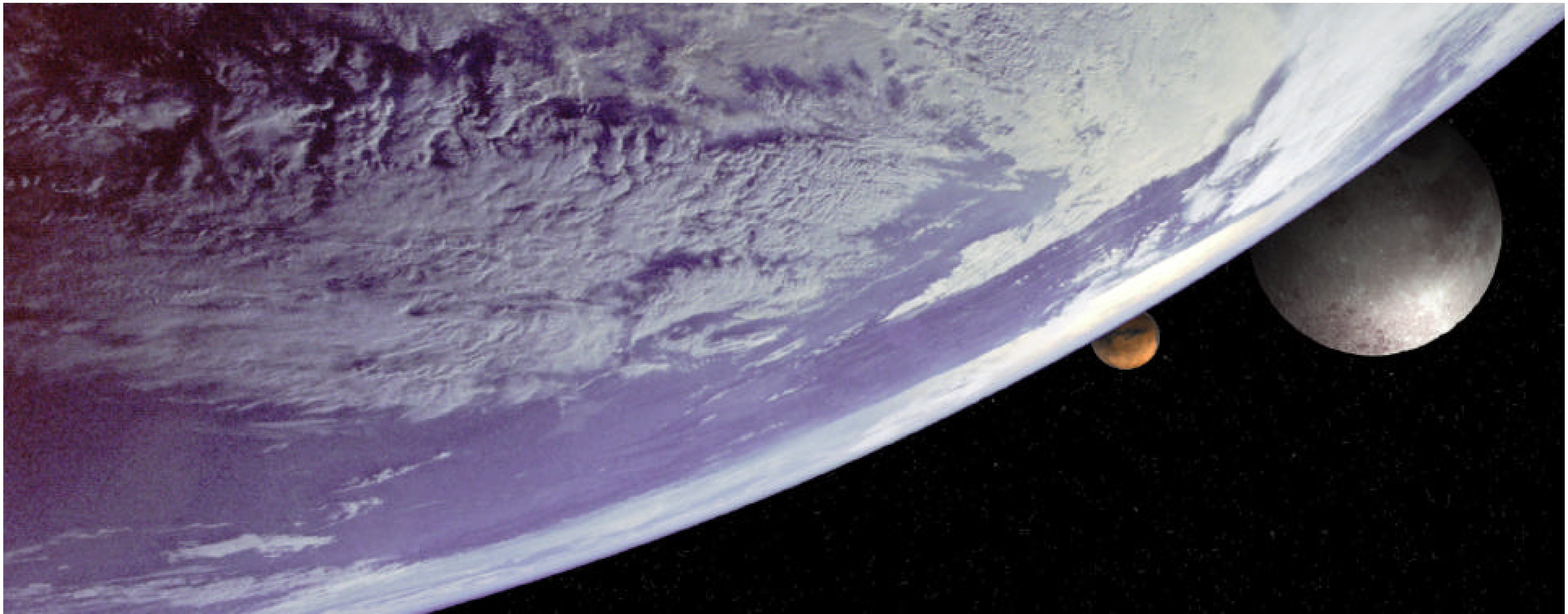


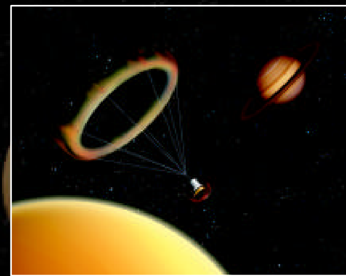
In-Space Propulsion

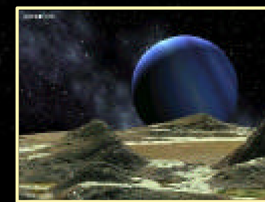
October 22, 2003

James R. Robinson

Program Executive

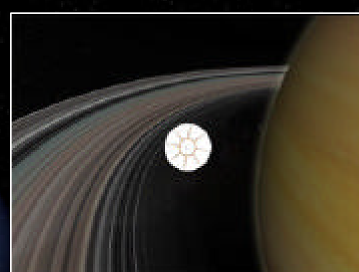
NASA HQ



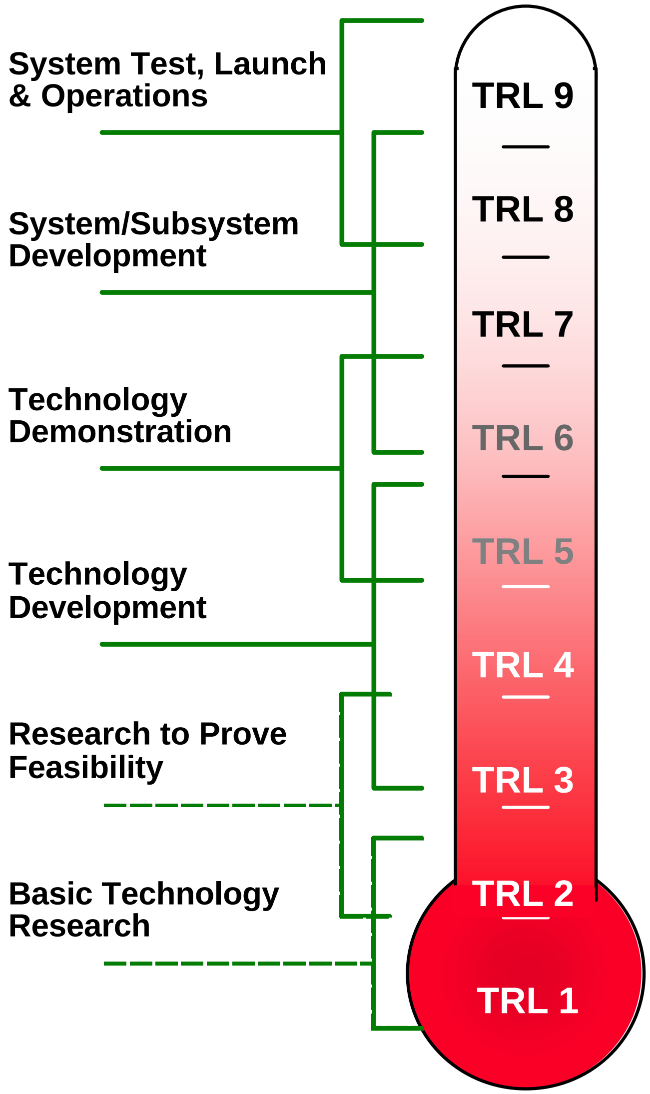


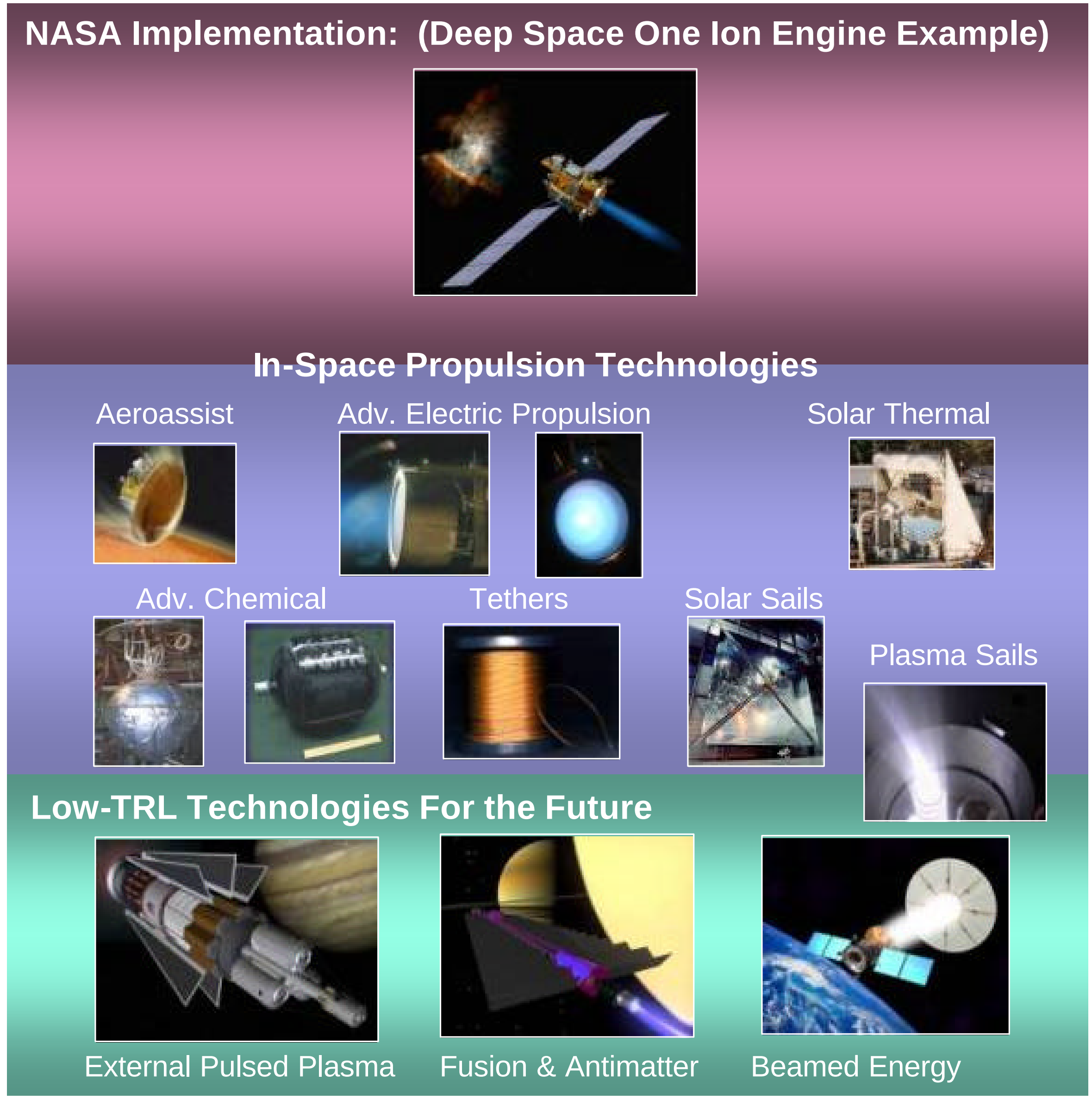
ISP Objective:

To develop in-space propulsion technologies that can enable and/or benefit near and mid-term NASA science missions by significantly reducing cost, mass, and/or travel times.



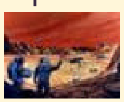
In-Space Propulsion Program Will Advance Mid-TRL Technologies to Support NASA Mission Applications





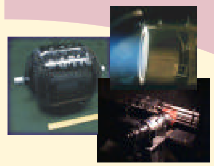
In Space Propulsion Technology
FY01 Prioritization Process

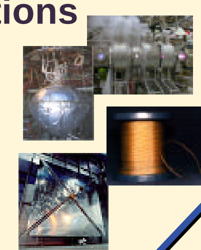
Requirements/Goals Established
- Space Science
- Earth Science
- Exploration and Development



Requirements provided by
NASA Enterprise customers

Technology Options Identified





Systems Concepts Developed
- Architecture
- Safety/Reliability
- Cost, Trip Time, etc.

Systems Concepts Compared
- Feasibility
- Identification of Technology Drivers
- Recommended approaches

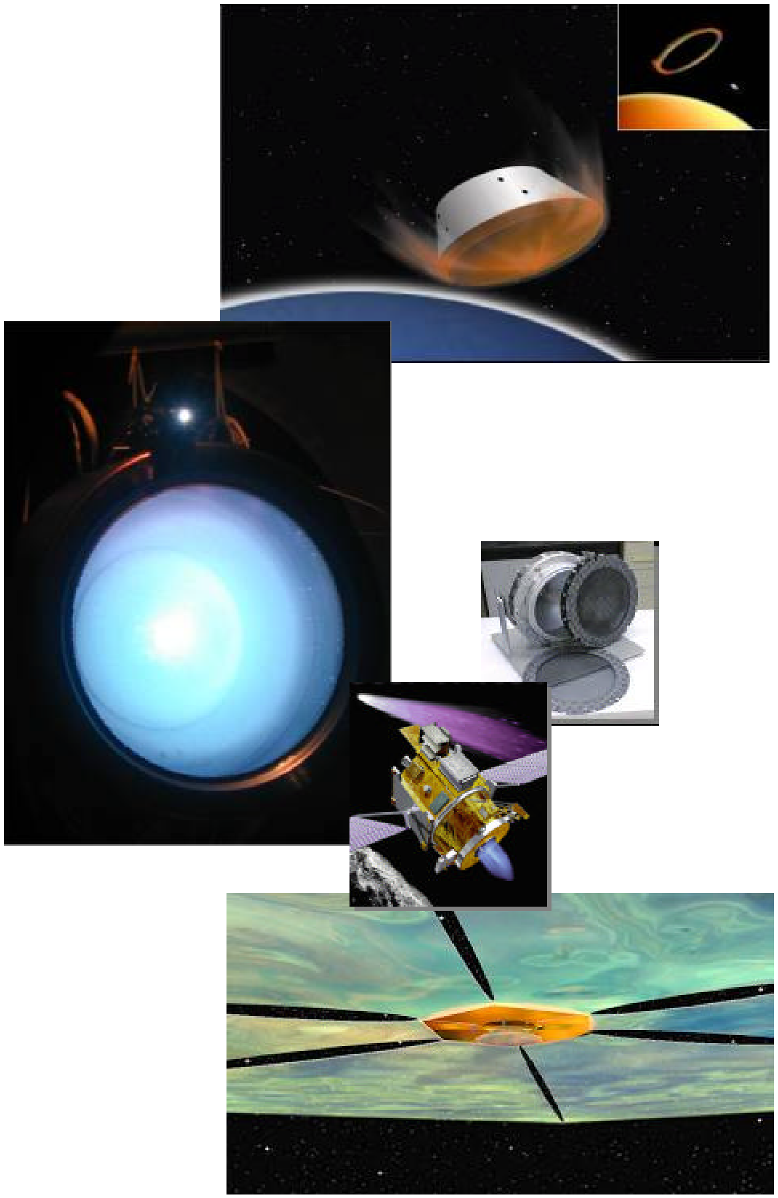
Technologies Prioritized (scoring process)

High Priority	Medium Priority	Low Priority	High Payoff/High Risk
Aerocapture	Advanced Chemical	Solar Thermal	Solar Sails 1 g/m2
Next Generation Ion Propulsion (5/10 kW)	SEP Hall (100 kw)		Momentum Exchange Tethers
Solar Sails			Plasma Sails

Cross-Enterprise In-Space Propulsion Priorities

- **Nuclear Propulsion technologies were transferred to NSI/Project Prometheus in FY03.**

In-Space Transportation Technology Descriptions
High Priority Technologies

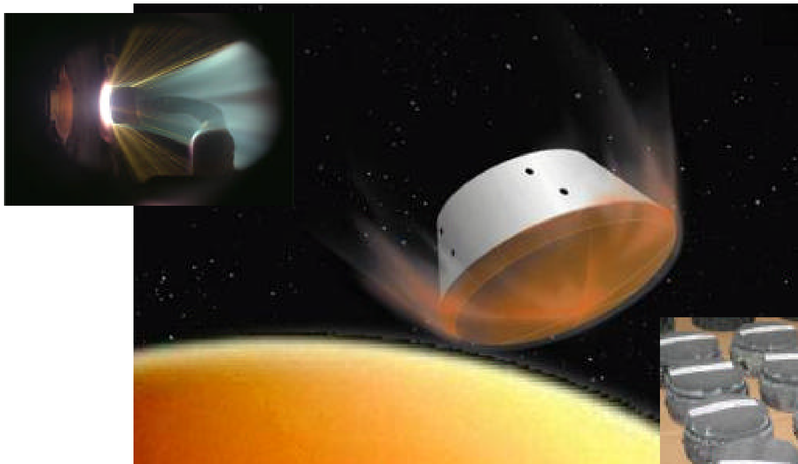


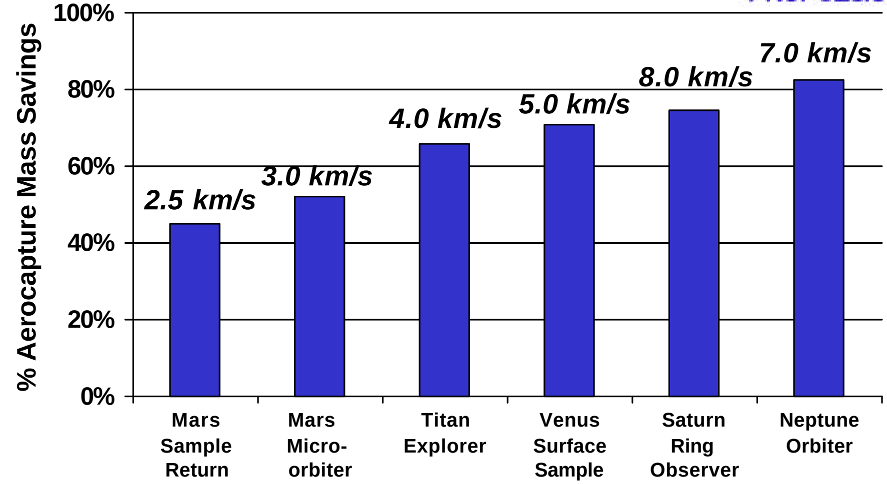
- **Aerocapture**
  Aerocapture is a member of the Aeroassist family of technologies. Aeroassist technologies use the aerodynamic forces during atmospheric flight to accomplish transportation function. Aerocapture is the use of an atmosphere, by the vehicle, to insert into an elliptical orbit from a hyperbolic orbit. This provides significant mass and travel time savings.

- **Next Generation Ion Thruster**
  Already a proven In Space propulsion technology, Ion thrusters utilize electrical energy to produce an electrostatic reaction (with a propellant) to obtain thrust. Technologies developed under this effort will increase Isp by greater than 30% over today's SOA ion engine, while significantly increasing power and thrust and reducing system alpha.

- **Solar Sails**
  Solar Sails use photon "pressure" or force on thin, lightweight reflective sheets to produce thrust. A near propellantless propulsion system, Solar Sails can open up new regions of the solar system to accessibility for important science missions. They may enable missions with Non-Keplarian orbits to the Earth-Sun libration point vicinity and provide high DV for Inner solar system sample return missions, high inclination orbits around the sun and interstellar precursor missions

Aerocapture





All values are compared to the mass of an all-propulsive capture.
Equivalent ΔV from Aerocapture noted above each column.

Technology Description:

Aerocapture technology uses the atmospheres of bodies to reduce the speed of a vehicle allowing for quick, near-propellantless orbit capture. The atmosphere is used as a brake, transferring the energy associated with the vehicle's high speed into thermal energy.

Benefits:

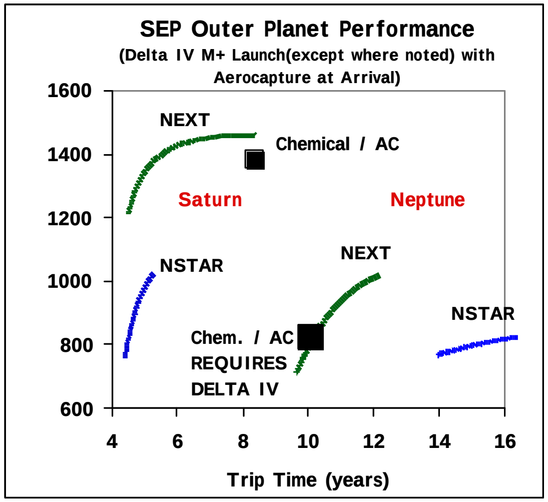
- Capable of high delta V at target arrival (multi-g deceleration).
- Significant reduction in trip times to outer planets (by allowing higher Earth departure or encounter energies).
- No or very little propellant required for orbit insertion/entry; saves mass which can save cost or enable greater scientific return.
- Autonomous aerodynamic control technology also enables precision landing.

Technology Area Status

- Four awards developing advanced TPS concepts, structures and adhesives to enable a low-mass aeroshell with integrated TPS – hardware development and tests are underway
- Trade Studies, conceptual design, and hardware development and testing in the areas of advanced aerodynamic decelerators (trailing ballutes, attached ballutes and inflatable aeroshells)
- Heat flux and recession sensors in development for rigid aeroshells. Preliminary sensor design complete, fabrication underway.
- In-depth systems definition studies of aerocapture at Titan and Neptune complete. Systems definition study of aerocapture at Mars and Venus to begin in FY05.

Next Generation Electric Propulsion

GRC's NEXT Thruster



Technology Description

Electric propulsion is most broadly defined as the acceleration of propellants by electrical heating, electric body forces, and/or magnetic body forces. Electric propulsion devices are capable of generating low thrust for long periods of time. The final velocities for many destinations are at least the same or higher than that achieved with chemical propulsion, because electric rockets accelerate much longer.

General Benefits:

- Low propellant consumption (?V. High performance)
- Reduced insertion mass, lower launch costs
- Reduced planetary trip times
- Reduced propulsion /payload mass fractions over SOA chemical

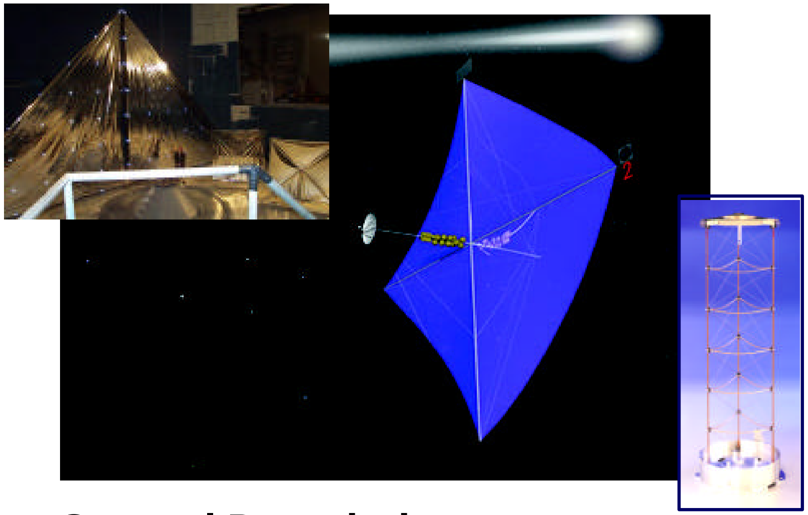
Ion Propulsion Technology Status:

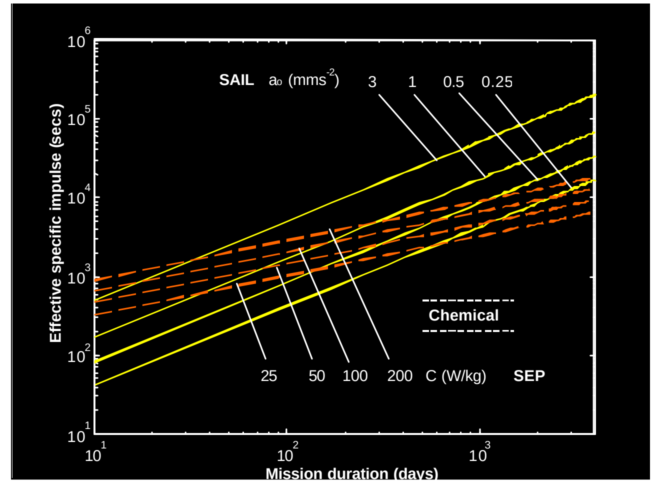
- The ground test of the NSTAR Ion engine completed over 30,000 hours of thruster operation, demonstrating >225 kg of propellant throughput – hardware is currently being analyzed to provide thruster "wear" data to ongoing thruster development efforts.
- Development of NASA's advanced Ion Propulsion system (NASA's Evolutionary Xenon Thruster - NEXT) at GRC has already produced a EM 40-cm thruster, a breadboard PPU, and a breadboard PMS. These subsystem components have been successfully integrated and tested in a single string system test. On-going efforts will develop flight-prototype and engineering model units for long duration life and multi-thruster system testing. NEXT is expected to reach TRL 6 in CY2006, except for full life testing. Advancements over state of the art (NSTAR) are provided below.

Thruster Attribute	*NSTAR*	*NEXT*
Max. Input Power, kW	2.3	Up to 7
Throttle Range	4:1	Up to 7:1
Max. Specific Impulse, S	3,170	4,050
Efficiency @ Full Power	62%	68%
Propellant Throughput, kg	83 design	>270
Specific Mass, kg/kW	3.6	~2.5

- Other technology activities include development of Carbon-based Ion Optics for 40-cm Ion thrusters (Pyrolytic-Graphite & Carbon-Carbon grids)

Solar Sails





General Description:

Propellantless propulsion utilizes solar photon pressure to obtain thrust. Sail film is compactly stowed for launch and deployed/supported by ultra-light weight trusses.

Technology Benefits:

- No propellants required
- Low system complexity (challenge is scaling to large area with ultra-low density)
- Low environmental impact on payload
- Enables access to previously inaccessible orbits (e. g., non-Keplerian, fixed reference, and high solar latitudes, etc.)

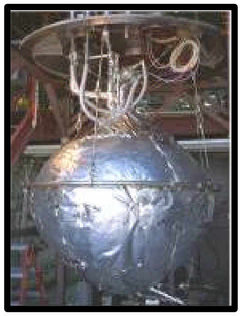
Technology Area Status:

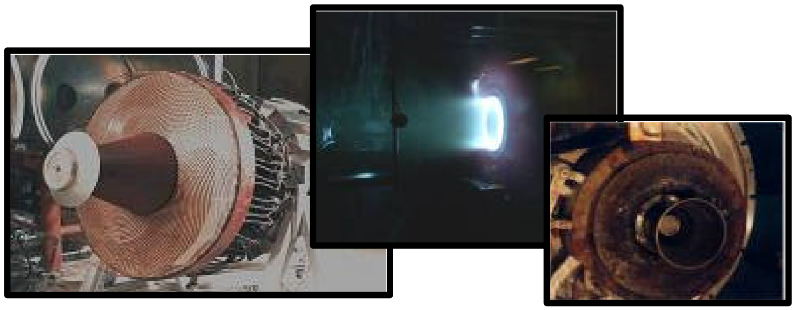
- Two awards to design, fabricate and test competing Sail concepts for system level ground demonstration
    - 10 m Ground demonstrations planned for mid FY04
    - 20 m Ground demonstration planned for mid FY05
- Multiple awards to develop and test high-fidelity computational models, tools, and diagnostics.
- Long term environmental evaluation of ultra-thin sail material

In-Space Transportation Technology Descriptions

Medium / Low Priority Technologies

Medium Priority:

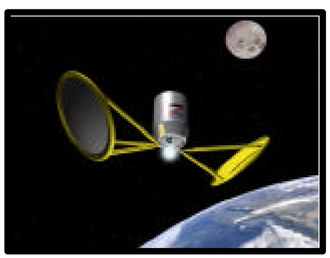




- **Advanced Chemical**
  Chemical propulsion systems have historically been the primary means for transportation of payloads in space because they generate the very large amounts of thrust required to overcome the effect of Earth's gravity. Investments will provide incremental improvements over SOA in the following areas:
  - Advanced Propellant development
  - Cryogenic Fluid Management
  - Lightweight components

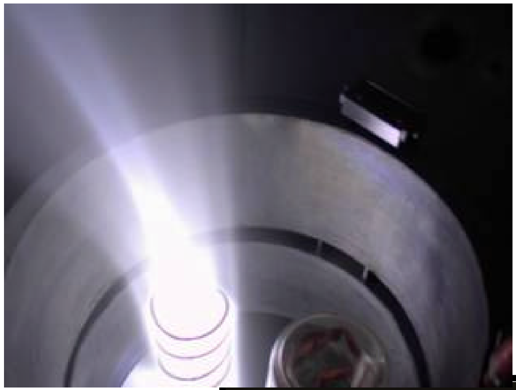
- **kW Solar Electric Propulsion (SEP)**
  This area pursues technologies to increase the performance of SEP systems by going to higher power levels, longer life technologies, and by increasing overall system efficiencies.

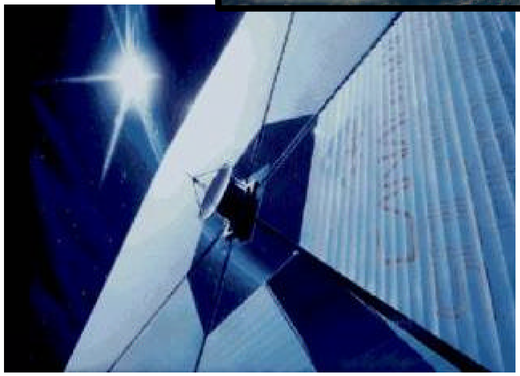
Low Priority:



- **Solar Thermal Propulsion**
  A solar thermal propulsion system consists of three basic elements: a Concentrator which focuses and directs incident solar radiation, a Thruster/absorber which receives solar energy, heats and expands propellant (hydrogen) to produce thrust, and a Propellant system which stores cryogenic propellant for extended periods and passively feeds it to the thruster/absorber. Due to fundamental technical issues and questions as to applicability to customer needs, technology investments in this area are under further study.

In-Space Transportation Technology Descriptions
High Risk/High Payoff Technologies





- **Plasma Sails**
  This technology is based on the transfer of momentum from the solar wind to an artificial magnet field structure similar to what naturally occurs at all magnetized Planets in the solar system, called a planetary Magnetosphere. A plasma sail differs from a solar sail in that electromagnetic / electrostatic fields are used to create and stabilize an area that exchanges momentum with solar wind, solar photons, or both.

- **Momentum Exchange Tethers**
  Momentum-exchange/electrodynamic reboost (MXER) tether is a rotating tether facility in Earth orbit which will boost. spacecraft to high-energy, pre escape trajectories. The rotating tether provides up to 90% of ΔV required for Earth escape. Electrodynamic propulsion can reboost the tether facility with little propellant.

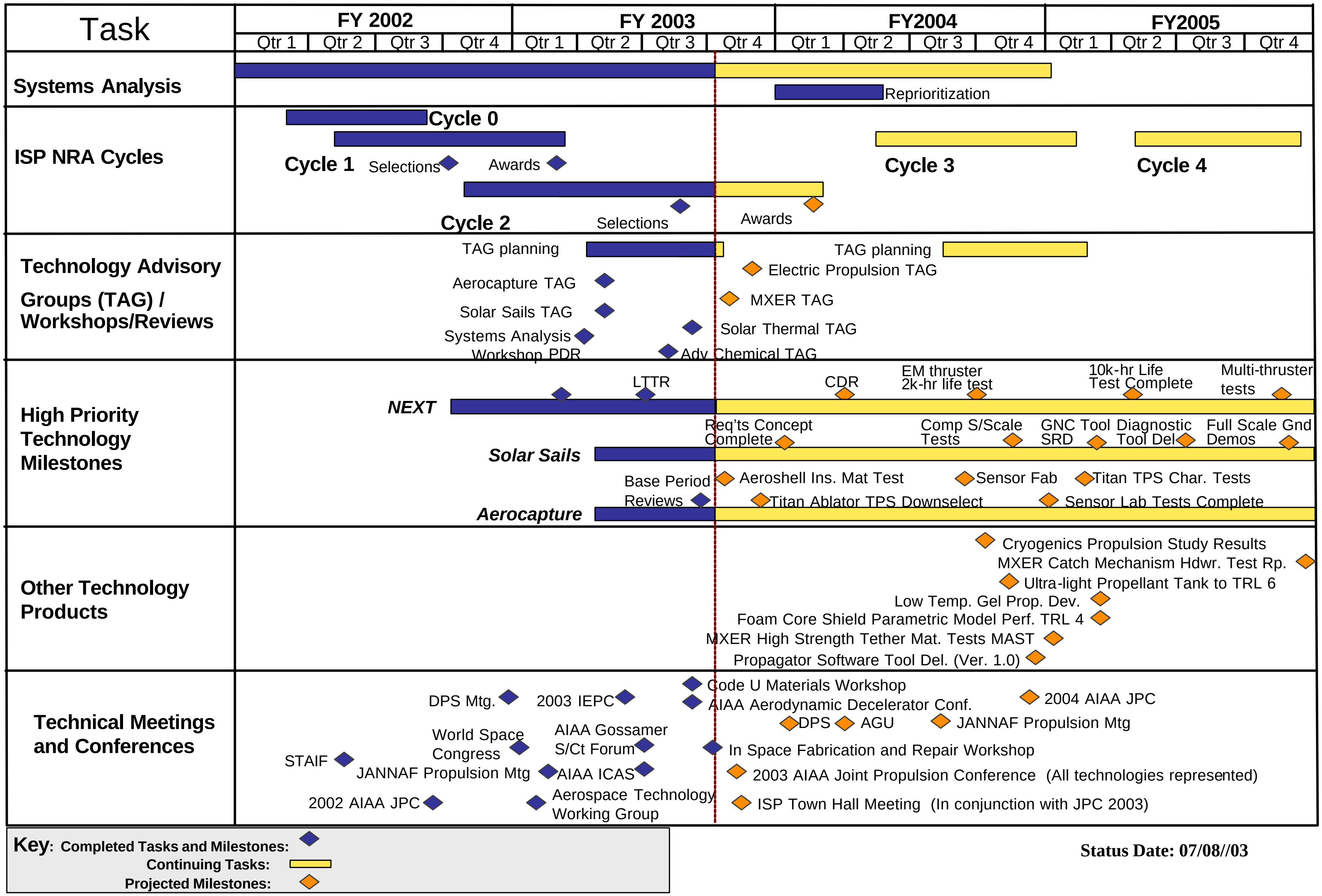
- **Ultra light Solar Sails (< 1g/m2)**
  Technology research and development in the areas necessary to bring the areal density of a Solar Sail system to less than 1 g/m2. May include ultralight materials and coatings, smart materials and structures, lightweight, high strength gossamer structures, innovative trajectory design, etc.

Program Status & Organization

In-Space Propulsion Program Status

- In-Space Propulsion is a HQ, Space Science, managed program
  - Orlando Figueroa, Program Manager
  - James Robinson, Program Executive
  - MSFC is delegated to be the implementing organization for ISP
  - Program is currently operating under a Formulation Authorization Document
- Competed efforts
  - Two awards made under an NRA specific to the Next Generation of Ion Electric Propulsion technologies
  - Additional awards In Space Propulsion Technologies, Cycle 1 solicitation (Aerocapture – 6 awards, Solar Sails – 3 Awards, Electric Propulsion for NEP and Power Conversion – 6 awards (managed at GRC under Prometheus)) under the Research Opportunities in Space Sciences (ROSS) NRA
  - In-Space Propulsion Technologies NRA, Cycle 2 (Aerocapture – 2 selections, Advanced Chemical – 5 selections, kW Solar Electric Propulsion – 2 selections, Momentum Exchange Tethers – 6 selections, and Solar Sails – 7 selections) released utilizing the ROSS NRA. Announcements were made May 16, 2003
- Directed efforts
  - Eight directed tasks underway for FY03
  - Nine planned directed tasks for FY04
  - Program Management and the majority of Systems Analysis efforts are considered directed funding

ISPTP Office Schedule



Status Date: 07/08//03

Cycle 1 NRA Awards - Aerocapture

Title	Center Awarded	Contract Awarded
Aerocapture		
Aeroshell Development for Aerocapture	**NASA Ames Research Center**	
Microsensor & Instrumentation Technology for Aerocapture		**ELORET Corporation**
Technology Development of Ballute Aerocapture		**Ball Aerospace**
High-Temperature Structures for Reduced Aeroshell Mass	**NASA Langley Research Center**	
Advanced Ablator Families for Aeroassist Missions		**Applied Research Associates**
Aerocapture Technologies		**Lockheed/Martin**

Cycle 2 NRA Selections - Aerocapture

Title	Center Awarded	Contract Awarded
Aerocapture		
Clamped Ballute Aerocapture Technology Development of Attached Inflatable Afterbody Decelerator		**Ball Aerospace**
Design, fabrication and test of Inflatable Aerocapture Concept		**Lockheed/Martin**

NRA Status - NGEP

Title	Center Awarded	Contract Awarded
Cycle 0 - Next Generation Ion (awards)		
NASA Evolutionary Xenon Thruster (NEXT)	**NASA Glenn Research Center**	
Carbon Based Ion Optics	**Jet Propulsion Lab**	**Boeing**
Cycle 2 – kW Solar Electric Propulsion (selections)		
High Voltage Hall Accelerator Program	**NASA Glenn Research Center**	
High Performance Bismuth Fueled Hall Thruster		**Busek Co., Inc.**
Propellant Management System demo with 40-cm Ion thruster		**VACCO**

Cycle 1 NRA Awards – Solar Sails

Title	Center Awarded	Contract Awarded
Solar Sails		
Ground System Demonstration Sail, Boom, Attitude Control, Deployment Mechanism		**AEC**
Ground System Demonstration Sail, Boom, Attitude Control, Deployment Mechanism		**L'Garde**
Guidance, Navigation, and Control Toolkit Mission Analysis Software; Flight Controller Software	**NASA Jet Propulsion Laboratory**	

Cycle 2 NRA Selections - Solar Sails

Title	Center Awarded	Contract Awarded
Solar Sails		
Optical Diagnostics System for Solar Sails	**NASA Langley Research Center**	
Advanced Computational Models and Software for Design and Simulation of Solar Sails Including Experimental Validation	**NASA Langley Research Center**	
Structural Analysis & Synthesis Tools for Solar Sails	**NASA Jet Propulsion Laboratory**	
Development of a Low-Cost, Low-Mass, Low-Volume, and Low-Power Attitude Determination and Control System (L4-ADCS) and High-Fidelity Computational Models of Solar Sail Systems		**Arizona State University**
Laboratory Characterization of Candidate Solar Sail Material	**NASA Marshall Space Flight Center**	
Superstring Ultralight Truss Boom for Solar Sails		**U. S. Naval Research Laboratory**
Advanced Manufacturing Technologies for Solar Sails using Processes Developed Specifically for Production of Ultra-thin Solar Sail Materials for Near, Mid and Far Term Space Science Missions		**SRS Technologies**

Cycle 2 NRA Selections - Advanced Chemical

Title	Center Awarded	Contract Awarded
Advanced Chemical		
Low Temperature Gel Propellant Technology		**Northrop Grumman Space Technology**
Cryogenic Propulsion with Zero Boil-Off Storage Applied to Outer Planetary Exploration	**NASA Jet Propulsion Laboratory**	
Lightweight, Foam Core Covers for Protection of Propellant Tanks and Propulsion Components	**NASA Jet Propulsion Laboratory**	
Ultra-light Tank Technology for In-Space Applications	**NASA Jet Propulsion Laboratory**	
LightWeight, Reliable Xenon Feed System Components for In-Space Electric Propulsion Based on All Metal ChEMS™ Manufacturing Technology*		**VACCO Industries, Inc.**

***: Managed under Next Generation Electric Propulsion**

Cycle 2 NRA Selections - MXER

Title	Center Awarded	Contract Awarded
Momentum-eXchange/Electrodynamic Reboost (MXER) Tether		
TetherSim-MX		**Tethers Unlimited, Inc.**
Hoytether Structures		**Tethers Unlimited, Inc.**
Software Tool for MXER		**Smithsonian Astrophysical Observatory**
Capture Device Concepts		**Tennessee Technological University**
Lightweight Catch Mechanism		**Lockheed/Martin**
MXER High Tensile Strength Tether		**Lockheed/Martin**

Directed Technology Tasks
FYO3

Task Name	*Lead Center*
Next Generation Electric Propulsion (NGEP)	
Analysis of the NSTAR Extended Life Test Data	JPL
High Power Hall Thruster Technology	GRC
Aerocapture	
None	
Solar Sail	
Environmental Characterization of Candidate Solar Sail Materials	MSFC
MXER Tether	
Survivable & Health Monitored MXER Tether Technology	MSFC
Advanced Chemical	
Protoflight Development Test for Zero Boil Off	GRC
Cryogenic Pressure Control in Orbit	MSFC
Solar Thermal	
Solar Thermal Technology Component Testing	MSFC
Integrated Solar Concentrator System Demonstration	GRC
Plasma Sail	
Plasma Sail Test Bed	MSFC

Directed Technology Tasks
FYO4

Task Name	*Lead Center*
Next Generation Electric Propulsion (NGEP)	
Analysis of the NSTAR Extended Life Test Data	JPL
High Power Hall Thruster Technology	GRC
Aerocapture	
Arc-Jet Testing of Existing Advanced Ablator Samples	JSC
Solar Sail	
Smart Adaptive Structures Performance Validation and Verification	MSFC
Life Test of Solar Sail Material in Simulated Space	MSFC
MXER Tether	
Advanced Material Field Emission Cathode Testing in Simulated Tether Environments	JPL
Advanced Chemical	
Cryogenic Pressure Control in Orbit	MSFC
Solar Thermal	
Solar Thermal Technology Component Testing	MSFC
Integrated Solar Concentrator System Demonstration	GRC
Plasma Sail	
None	